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Article

Influence of Tillage Systems and Selective Herbicides on Weed Management and Productivity of Direct-Seeded Rice (*Oryza sativa*)

*Efeito de Sistemas de Cultivo e Herbicidas Seletivos no Manejo de Plantas Daninhas e na Produtividade de Arroz em Semeadura Direta (**Oryza sativa**)*

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ABSTRACT - Weeds cause considerable damage to rice crop. To ascertain the influence of different weed management practices under different tillage systems, a field experiment was conducted during 2014-15. Experimental design was RCB with split-plot arrangement and with a net plot size of 6 x 2 m. Three tillage systems *viz*; zero tillage with glyphosate application and conventional tillage with and without stale seed bed, and seven weed management treatments *viz*; weedy check, manual weeding, oxadiargyl as pre-emergence, pyrazosulfuron as pre-emergence, pyrazosulfuron as post-emergence, fenoxaprop-ethyle + sodium fluoride as post-emergence and fenoxaprop-ethyle + sodium fluoride as post-emergence. Results revealed that all treatments including tillage systems and herbicides significantly ($p<0.05$) affected weed density and weed dry biomass. Minimum weed density (229.22, 159.22 and 127.77 m^{-2}) and weed dry biomass (68.01, 49.29 and 41.08 g m^{-2}) at 30, 45 and 60 DAS (days after sowing) were recorded for pyrazosulfuron (as pre-emergence), respectively, followed by fenoxaprop-ethyle + sodium fluoride (as post-emergence). Maximum 1000-kernel weight and kernel yield (19.15 g and 3.45 ton ha^{-1}) were recorded for weed free treatments and it was 12 and 57% higher than weedy check. Maximum net benefit and benefit to cost ratio (USD$ 817 ha^{-1} and 1.76, respectively) were recorded for pyrazosulfuron applied at either pre- or post-emergence stage under zero tillage system. Conclusively, pyrazosulfuron (as pre-emergence) and fenoxaprop-ethyle + sodium fluoride (as post-emergence) gave the best weed control under conventional tillage with stale seed bed system, while pyrazosulfuron exhibited maximum benefit-cost ratio under zero tillage system.

Keywords: *Oryza sativa* L., direct-seeded rice, tillage systems, herbicides, integrated weed management.

RESUMO - Plantas daninhas causam dano considerável à colheita de arroz. Para averiguar a influência de diferentes práticas de manejo de plantas daninhas sob diferentes sistemas de cultivo, um teste de campo foi conduzido durante 2014 -15. Como desenho experimental foram utilizados blocos inteiramente casualizados com parcelas subdivididas, cada uma de 6 x 2 m. Foram testados três sistemas de cultivo: plantio direto com aplicação de glifosato, cultivo convencional com pré-germinação de plantas daninhas ("stale seedbed tecnique") e cultivo convencional sem pré-germinação de plantas daninhas. Sete tratamentos de manejo de plantas daninhas foram aplicados: "weedy check (controle com ervas daninhas)", controle manual, oxidiargil pre-emergência, pyrazosulfuron pré-emergência, pyrazosulfuron pós-emergência, fenaxapropetil + sódio fluorido pós-emergência. Resultados revelaram que todos os tratamentos inclusive sistemas cultivo e herbicidas afetaram

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significativamente ($p<0.05$) a densidade e a biomassa seca de plantas daninhas. A menor densidade (i.e. 229.22, 159.22 e 127.77 m^{-2}) e menor biomassa seca (i.e. 68.01, 49.29 e 41.08 g m^{-2}) de plantas daninhas foram registradas em 30, 45 e 60 (dias após semeadura) para pyrazosulfuron (como pré-emergência), respectivamente, seguido por fenoxapropetil + sódio fluoreto (como pós-emergência). O peso máximo de 1000 grãos e máxima produção (i.e. 19.15 g e 3.45 ton ha^{-1}) foram registrados para tratamentos livres de plantas daninhas, que produziram 12 e 57% mais do que "weedy check". Máximo benefício líquido e maior relação benef)cio/custo (i.e. USD 817 ha^{-1} e 1.76, respectivamente) foram registrados para pirazosulfuron aplicado tanto em pré como em pós-emergência sob plantio direto. Finalmente, pirazosulfuron (pré-emergência) e fenoxapropetil + fluoreto de sódio (pós-emergência) foram os tratamentos mais eficientes para controle de plantas danihas sob cultivo convencional com pré-germinação de plantas daninhas, enquanto pirazosulfuron proprocionou o melhor benef)cio/custo sob plantio direto.

Palavras-chaves: *Oryza sativa* L., arroz em semeadura direta, sistemas de cultivo, herbicidas, manejo integrado de plantas daninhas.

INTRODUCTION

Rice is consumed as a staple food by more than half of the world population (Chauhan and Johnson, 2011). It is the primary source of revenue and livelihood for more than 100 million families in Asia and Africa (FAO, 2004). Conventionally, using transplanting technique for rice cultivation in which first rice nursery is growing on beds and then nursery seedling are transplanted after 30-40 days and flooded field (Ehsanullah et al., 2007; Chauhan, 2012). This method not only suppresses weeds but also provides an enhanced growing environment to the rice plants. However, this transplanting method usually needs a large quantity of water available to the crop for the entire growth period (Bhushan et al., 2007; Rao et al., 2007; Chauhan and Johnson, 2011; Sartori et al., 2013). Resource conservation technologies are becoming important in rice-wheat systems because these help to reduce the cost of production (Singh et al., 2006). Among rice growing systems, direct-seeded rice (DSR) is an alternate strategy to tackle the issues of water scarcity and labour shortage (Ladha et al., 2003; Bhushan et al., 2007; Weerakoon et al., 2011). The yield of direct-seeded rice crop is usually at par with transplanting and the net return is higher (Singh et al., 2005).

However, in direct-seeded rice weed plants pose serious problem and cause yield loss both in terms of quantity and quality (Chauhan and Johnson, 2009; Chauhan and Opena, 2012; Chauhan et al., 2012; Muhammad et al., 2016). It has been found that weeds compete with crop plants for nutrients, water and light and cause yield losses in rice up to 4,880 kg ha^{-1} (Ferrero, 2003; Zhang et al., 2003). Critical periods for weed control were assessed at between 10 to 32 days after sowing (DAS) in wet seeding and up to 83 DAS in dry seeding (Johnson et al., 2004; Sharma et al., 2006). As the weeds and rice emerge simultaneously in DSR, proper time and method of weed control remains a difficult occurrence (Khaliq and Matloob, 2011). An operative and early weed management tactic is essential for any DSR production technology levelling at attaining higher productivity and effectiveness (Rao et al., 2007a; Jaya-Suria et al., 2011).

Different weed control choices are open for rice crop such as tillage systems, manual weeding, herbicides, competitive cultivars, seeding density, water management, fertilizer management, seed invigoration and mulching and all these weed control strategies are helpful to increase rice yield (Rao et al., 2007b; Khaliq et al., 2012a; Sana et al., 2017). Tillage operations have been an integral component of the crop husbandry, providing appropriate environment for crop cultivation, growth and development. They greatly influence the composition of particular weed communities of the area (Buhler, 1995; Arif et al., 2007). Zero tillage has been favourable practice regarding alleviating soil degradation, enhancing water use efficiency and improving crop yield and farmer monetary benefits (Gupta and Sayre, 2007). Rice cultivation under zero tillage and reduced tillage usually reduces fuel expenditures, water losses and intensive manpower requirement, and enhance the physico-chemical characteristics of soil (Chauhan et al., 2006).

In DSR, chemical control of weeds using herbicides has appeared as a promising approach for weed management. It is easy, effective and economically feasible and has been expanded rapidly over years (Mukherjee and Singh, 2005; Khaliq et al., 2012a). Pre- and post-emergence application of synthetic weedicides effectively suppress weeds in DSR and provide a competition free environment to the direct-seeded fine rice (Pellerin and Webster, 2004; Baloch et al., 2005; Rao et al., 2007a; Khaliq et al., 2012b). Keeping in view the importance of rice and losses due to weeds in DSR, a field experiment was carried out with the aim to estimate the efficiency of some pre- and post-emergence herbicides for weed control in the direct-seeded rice crop grown under different tillage systems and to evaluate the agronomic and economic returns of DSR under different tillage systems and weed control methods.

MATERIAL AND METHODS

Study area

Study was carried out at the Agronomic Research Farm of the University of Agriculture, Faisalabad (Punjab, Pakistan) (31°26' N, 73°04' E). Soil of the experimental site is Aridisol (fine-silty, mixed, hyperthermic Ustalfic, Haplargid) as per USDA classification and Haplic Yermosols according to FAO classification. The physicochemical properties of soil of the experimental site are given in Table 1. Due to high evapotranspiration, Faisalabad features an arid climate with mean annual rainfall of about 200 mm. Meteorological data during the course of entire experimentation were obtained from Agro-Meteorological Observatory, Department of Crop Physiology of the University of Agriculture, Faisalabad.

Experimental design and treatments

Experiment was laid out according to Randomized Complete Block Design with split-plot arrangement and was conducted during summer (*kharif*) season, 2014 and was repeated in 2015 in order to find out the efficacy of different tillage systems and herbicide treatments on weed dynamics, yield and yield component of rice. Certified seeds of rice variety Super Basmati were sown by direct-seeding technique. The experiment comprised of three tillage systems *viz*; zero tillage with glyphosate, conventional tillage with no stale seed bed, conventional tillage with stale bed and seven weed management treatments *viz*; weedy check (control plot), manual weeding, oxadiargyl (Top star 80WP) at 100 g a.i. ha^{-1} as pre-emergence, pyrazosulfuron (Terminator 10 WP) at 250 g a.i. ha^{-1} as pre-emergence (just before sowing), pyrazosulfuron (Terminator 10 WP) at 250 g a.i. ha^{-1} as post-emergence (seven days after sowing), oxadiargyl (Top star 80WP) as pre-emergence plus fenoxaprop-ethyle (Puma Super 7.5 EW; at 82.25 a.i. ha^{-1} + sodium fluoride (Sun Star 15 WG) at 200 g a.i. ha^{-1} as post-emergence, and pyrazosulfuron (Terminator 10 WP) as pre-emergence plus fenoxaprop-ethyle (Puma Super 7.5 EW+ sodium fluoride (Sun Star 15 WG) as post-emergence.

Table 1 - Physical and chemical properties of soil of experimental site

Parameter	Value	Status
Texture class	Sandy loam soil	Medium Hard
EC (dSm^{-1})	0.43	Non Saline
pH	8.4	Medium Alkaline
Exchangeable Sodium (me100 g^{-1})	0.9	Medium
Organic Matter (%)	1.00	Medium
Nitrogen (%)	0.77	Medium
Phosphorus (ppm)	120	High
Exchangeable K (ppm)	104	Medium

Data recording

Weed density and weed biomass were recorded at 30, 45 and 60 days after sowing (DAS) using randomly selected quadrats of 1 m^2. Weeds within each quadrat were identified, counted and clipped off above the soil surface. Individual weeds were grouped into weed type (i.e. grasses, broad-leaved and sedges). Later on, these weed samples were oven dried at 700 °C for 72 h to determine dry biomass and for further analyses. Paddy rice yield was measured after harvesting randomly selected 1 m^2 areas in each plot.

Growth

Samples for growth analysis were collected from area of 20 cm × 50 cm. Then this was separated into leaves and stems. For leaf area measurement, 2 g sample was taken from each plot leaves. Remaining samples were sun dried for 24 h then oven dried for 48 h for the calculation of other growth parameters.

Leaf area index (LAI)

Plants were harvested fortnightly from 25 cm × 25 cm area from each plot and were analysed for leaf area and dry matter accumulation. Leaf area was measured with the help of a leaf area meter. Leaf area index was calculated as the ratio of leaf area to land area (Watson, 1947).

$$LAI = \text{leaf area } (cm^2) \;/\; \text{land area } (cm^2)$$

Leaf area duration (days)

Leaf area duration (LAD) for the entire growing season was estimated by using the following formula of Hunt (1978).

$$LAD = \{(LAI_1 + LAI_2)/2\} \times (t_2 - t_1)$$

where LAD = Leaf are duration; LAI_1 = Leaf area index at first harvest; LAI_2 = Leaf area index at final harvest; t_1 = Date of observation of first leaf area index; t_2 = Date of observation of final leaf area index.

Crop growth rate (g m^{-2} d^{-1})

Crop growth rate was measured using the following formula of Hunt (1978).

$$CGR = (W_2 - W_1)\;/(t_2 - t_1) \times 1/GA$$

where W_1 = Total dry matter at first harvest; W_2 = Total dry matter at second harvest; t_1 = Date of observation of first dry matter; t_2 = Date of observation of second dry matter; GA = ground area (m^2).

Net assimilation rate (NAR) (g m^{-2} d^{-1})

Net assimilation rate was measured by using the formula as proposed by Hunt (1978).

$$NAR = TDM \;/\; LAD$$

where NAR = Net assimilation rate; TDM = Final total dry matter at harvesting; LAD = Final leaf area duration at harvesting.

Plant height (cm)

Plant height at maturity was measured with a meter rod from the base of the plant to the leaf tip. Height of 10 tillers chosen randomly was measured in each plot and was averaged.

Number of tillers (m^{-2})

Tillers from an area of 100 cm × 100 cm were counted at random from three different places in each plot and averaged.

Number of productive and non-productive tillers (m^{-2})

Tillers from an area of 100 cm × 100 cm were counted at random from three different places in each plot and averaged.

Number of spikelet's per panicle

Ten panicles were harvested from each plot at maturity and placed in bags. After which each panicle was sketched on white paper and total number of spikelet's per panicle were calculated and averaged.

Number of kernels per panicle

Ten panicles were harvested from each plot at maturity and threshed. Their kernel were manually counted and averaged.

Panicle length (cm)

Twenty panicles were harvested from each plot from primary tillers at maturity and panicle length was measured and averaged.

1000-kernel weight (g)

Three samples of normal kernels from each replication and from each treatment were taken and 1000 kernel weight was recorded.

Kernel yield (kg ha^{-1})

The clean rough rice was air dried, bulked and weighed after harvesting and threshing. The kernel weight was adjusted to 14% moisture content and the yield of clean rough rice was calculated in kg ha^{-1}.

Straw yield (ton ha^{-1})

Produce of each plot was manually threshed by beating against a steel drum. The rice straw was weighed using a digital electronic balance. Weight in kg per plot was transformed into tons per hectare.

$$\text{Straw yield (ton ha}^{-1}) = \{\text{plot yield (kg) / plot size (m}^{2-})\} \times 10000 / 1000$$

Biological Yield (ton ha^{-1})

At physiological maturity, crop was manually harvested with a sickle. The harvested crop was tied into bundles and kept in respective plots for five days for sun drying. Biological yield was recorded in kg per plot by using a digital electronic balance and converted into tons per hectare.

$$\text{Biological yield (ton ha}^{-1}) = \{\text{plot yield (kg) / plot size (m}^{2})\} \times 10000 / 1000$$

Harvest index (%)

Harvest index (HI) was calculated as the ratio of kernel yield to biological expressed as percentage as per Beadle (1993).

$$\text{HI (\%)} = \{\text{kernel yield / biological yield}\} \times 100$$

Kernel quality traits

Abortive kernels (%)

Abortive kernels are those which do not attain full size as they stop growing during early stages of kernel development though fertilization does take place. They do not permit light to pass through them and look dull.

Opaque kernels (%)

Opaque kernels are those which attain full size but lack of carbohydrates make them translucent and overall dull chalky structure due to porous filling of starch also do not allow light to pass through them. As their development stopped at later stage therefore they were bigger than abortive kernels. They did not acquire normal size because of retarded development

Normal kernels (%)

Normal kernels are those that are translucent, attain full size, allow light to pass through them and show normal starch compaction. Number of sterile spikelet's, opaque, abortive and normal kernels from each sketch of all the treatments were counted, averaged and expressed in percentage. Total number of Spikelet's was counted from each sketch and was averaged. The clear, translucent, normal and without chalky spots kernels were recorded by excluding all the abnormal kernels from total number of spikelet's.

Chalky kernels (%)

Chalky kernels were separated on the basis of chalky area present on the kernels. Twenty kernels were placed in the front of light (Tungsten filament bulb) on working board. These were identified and expressed in present.

Statistical analysis

Statistix 8.1 software (Analytical software, Statistix; Tallahassee, FL, USA, 1985-2003) was used for data statistical extrapolation. Data on weed density and weed dry biomass were square root [√√(x þ 0.5)] transformed to improve the variance homogeneity. Analysis of variance (ANOVA) was performed to find out the effect of treatments on weed density and dry biomass and paddy rice yield parameters followed by Tukey's honest significance difference (HSD) test at significance level of 0.05 in order to compare the differences among the treatment means.

RESULT AND DISCUSSION

Weeds infestation has been a critical issue in cultivation of agronomic crops such as rice. The study consisted of *in situ* evaluation of the effect of different weeds management methods fewer than three different tillage systems on weed dynamics, yield attributes and economic parameters of direct-seeded aerobic rice. The results revealed a significant effect of tillage systems and weeds management methods on all parameters studied. Tillage system and weed management affected the diversity, density and dry biomass of different weed species infesting rice crop. The dominant weed type under conventional tillage was broad-leaved weeds, while grassy (narrow-leaved) weeds were dominant under zero tillage system. Singh et al. (2005) reported that nutsedge *Cyperus rotundus* (a grassy weed) was dominant weed plant in drill sown rice under zero tillage. Similarly, diminution in density of broad leaved weeds density by herbicide applications in direct-seeded rice has been acknowledged by many previous studies (Chauhan and Opena, 2012; Joshi et al., 2015).

Weed density and dry biomass at 30 DAS, 45 DAS and 60 DAS

Data regarding weed density recorded at 30, 45 and 60 DAS (Table 2) indicated a significant ($p<0.05$) influence of weed management treatments on weed density whereas their interactions with tillage systems were non-significant. The maximum weed density (433.44 at 30 DAS, 262.11 at 45 DAS and 210.11 at 60 DAS.) was observed in weedy check (control). Maximum reduction in weed density up to 47, 39 and 40% against weedy check (control) was observed at 30, 45 and 60 DAS respectively, where pyrazosulfuron (pre-emergence), fenoxaprop-ethyle + sodium fluoride (post-emergence). The maximum weed dry biomass i.e. 128.61, 81.14 and 67.55 g m^{-2} was observed in weedy check plot at 30, 45 and 60 DAS, respectively.

Maximum reduction in weed dry biomass up to 46, 38 and 39% was observed against control plot at 30, 45 and 60 DAS respectively where pyrazosulfuron (pre-emergence), fenoxaprop-ethyle + sodium fluoride (post-emergence). In this study, weed plants were efficiently managed, both in terms of density and dry biomass by all herbicide treatments. Maximum reduction of weed density and dry biomass were recorded for pyrazosulfuron (pre-emergence) + fenoxaprop-ethyle + sodium fluoride (post-emergence) i.e. Terminator followed by Puma Super + Sun Star. Khaliq et al. (2012b)

Table 2 **-** Influence of tillage systems and weed management practices on total weed density (m^2) at 30, 45 and 60 DAS in aerobic rice

Treatment	Weed density (m^2)			Dry weed biomass (g m^2)		
Tillage systems	30 DAS	45 DAS	60 DAS	30 DAS	45 DAS	60 DAS
Zero tillage	313.89	191.22	163.17	93.14	59.20	52.47
Conventional tillage without stale seed bed	311.56	183.72	162.00	92.45	56.88	52.09
Conventional tillage with stale seed bed	316.22	213.44	153.28	93.83	66.08	52.09
Weed management practices						
Weedy check	433.44 A	262.11 A	210.11 A	128.61 A	81.14 A	67.55 A
Oxadiargyl (pre-emergence)	322.33 B	203.22 B	169.55 B	95.64 B	62.91 B	54.51 B
Pyrazosulfuron (pre-emergence)	335.33 B	182.11 BC	161.22 B	99.50 B	56.38 BC	51.83 B
Pyrazosulfuron (post-emergence)	315.55 BC	202.11 B	153.55 B	93.63 BC	62.57 B	49.37 B
Oxadiargyl (pre- emergence) + fenoxaprop-ethyle + sodium fluoride (post-emergence)	247.44 BC	168 C	134.66 C	73.42 BC	52.01 C	43.30 C
Pyrazosulfuron (pre-emergence) + fenoxaprop-ethyle + sodium fluoride (post-emergence)	229.22 C	159.22 C	127.77 C	68.01 C	49.29 C	41.08 C

reported similar results that amalgamation of herbicides gave greater weed repression in aerobic rice than solitary of herbicides application. Similarly, Chauhan and Opena (2012) used chronological herbicides in aerobic rice and reported significant decreased in weed density as compared to weedy check. It was reported that combination of pre- and post-emergence herbicides applications recorded reduction in weed density over the sole application of some single herbicide (Khaliq et al., 2011).

Growth Parameters

Leaf area index (LAI) is an indicator of the size of assimilatory system of a crop. Leaf area duration (LAD) determines the importance of photosynthetic area during growth (emergence to maturity) and crop growth rate (CGR) is the rate of dry matter accumulation per unit of land area. LAI and LAD were gradually increased up to the end of grand growth stage and were affected by tillage systems and herbicide treatments (Figures 1 and 2). Maximum LAI and LAD were recorded for weed free plots under all tillage systems. LAI reached at peak at 3rd harvesting (75 DAS). Weedy check plots were quite pronounced regarding LAI and LAD minimum was receded at 1st harvesting stage (60 DAS) in all tillage systems. Results indicated that with the passage of time, CGR increased up to 70 DAS and then was decreased in between 70-85 DAS. Maximum CGR was showed in weed free plot under all tillage systems. CGR in all weed management treatments gradually decreased during 70-85 DAS. Among herbicides, application of pyrazosulfuron at pre-emergence stage and of pyrazosulfuron at post-emergence stage (70–85 DAS) gave the maximum CGR (Figure 3).

Net assimilation rate (NAR) is a dry matter produced per unit of leaf area. Figure 4 shows the pre and post-anthesis NAR. At Post-anthesis NAR showed less while Pre-anthesis NAR was higher in all treatments. Among herbicides, pyrazosulfuron at post-emergence stage and oxadiargyl at pre-emergence stage exhibited maximum pre- and post-anthesis NAR. Weed free treatment recorded moderately minimum pre- and post-anthesis NAR than other herbicide treatments (Figure 4).

In brief, maximum LAI and LAD values were exhibited by plots treated with sequential herbicide applications i.e. pyrazosulfuron (pre-emergence) + fenoxaprop-ethyle + sodium fluoride

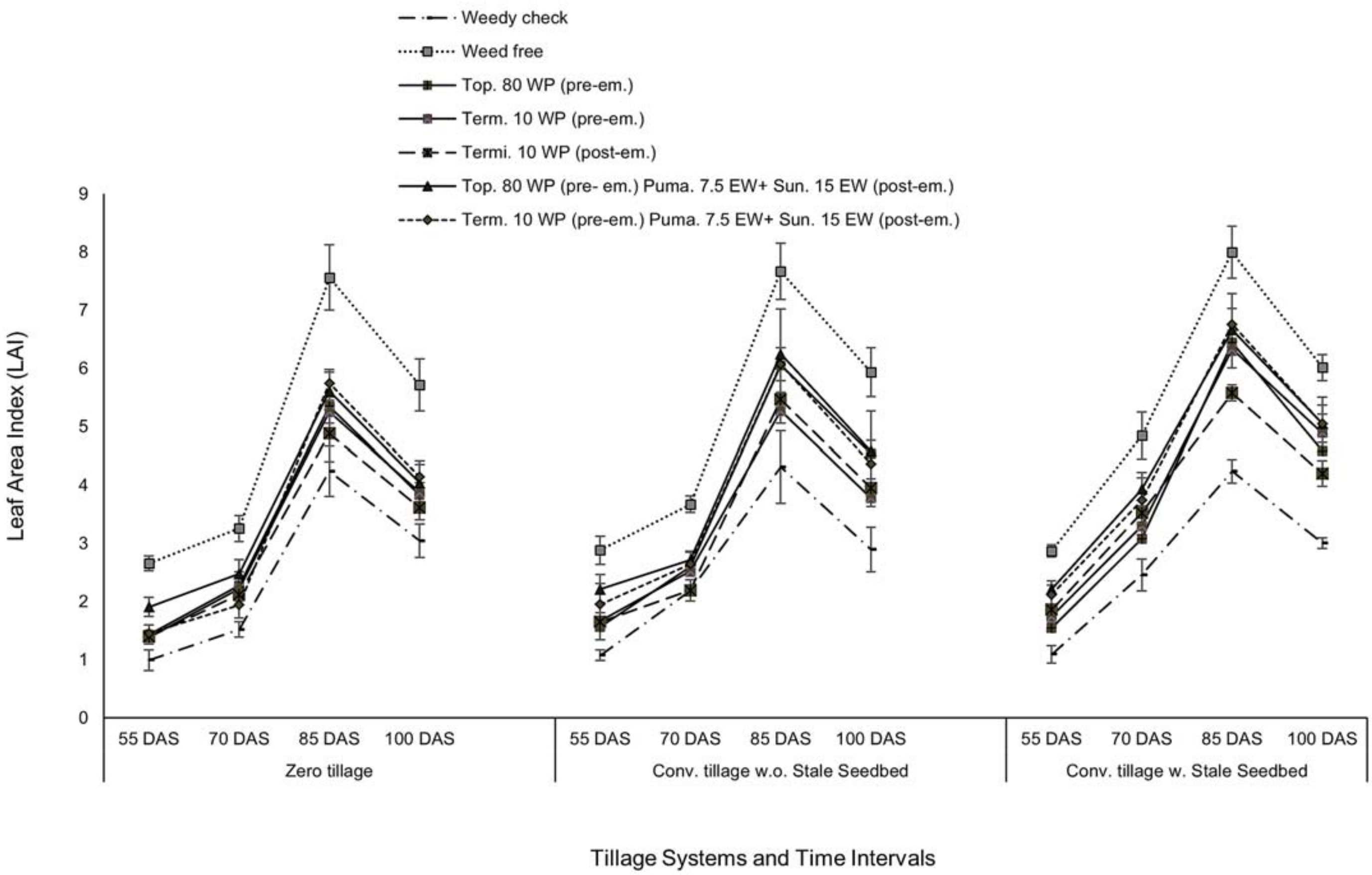

Figure 1 **-** Influence of weed management treatments on Leaf Area Index (LAI) (days) in aerobic rice grown under different tillage systems.

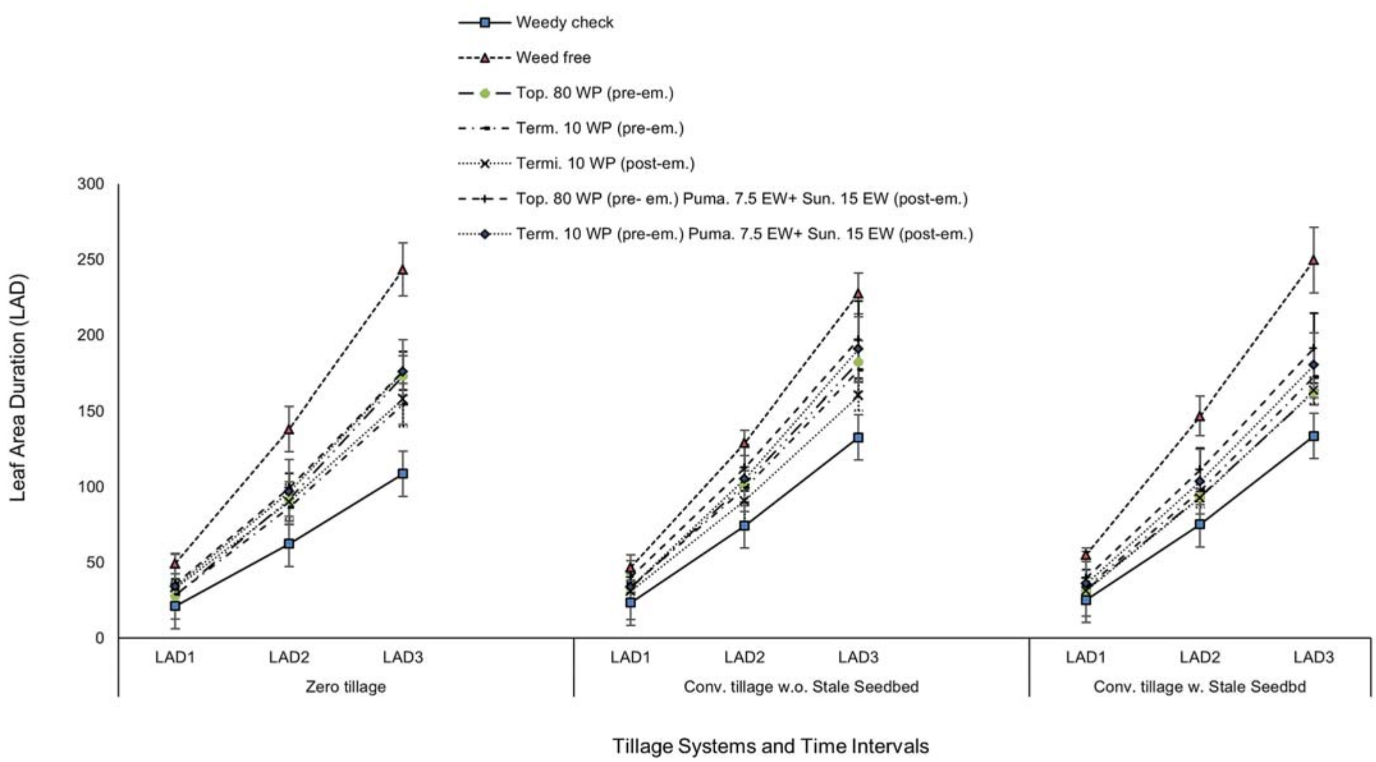

Figure 2 **-** Influence of weed management treatments on Leaf Area Duration (LAD) (days) in aerobic rice grown under different tillage systems.

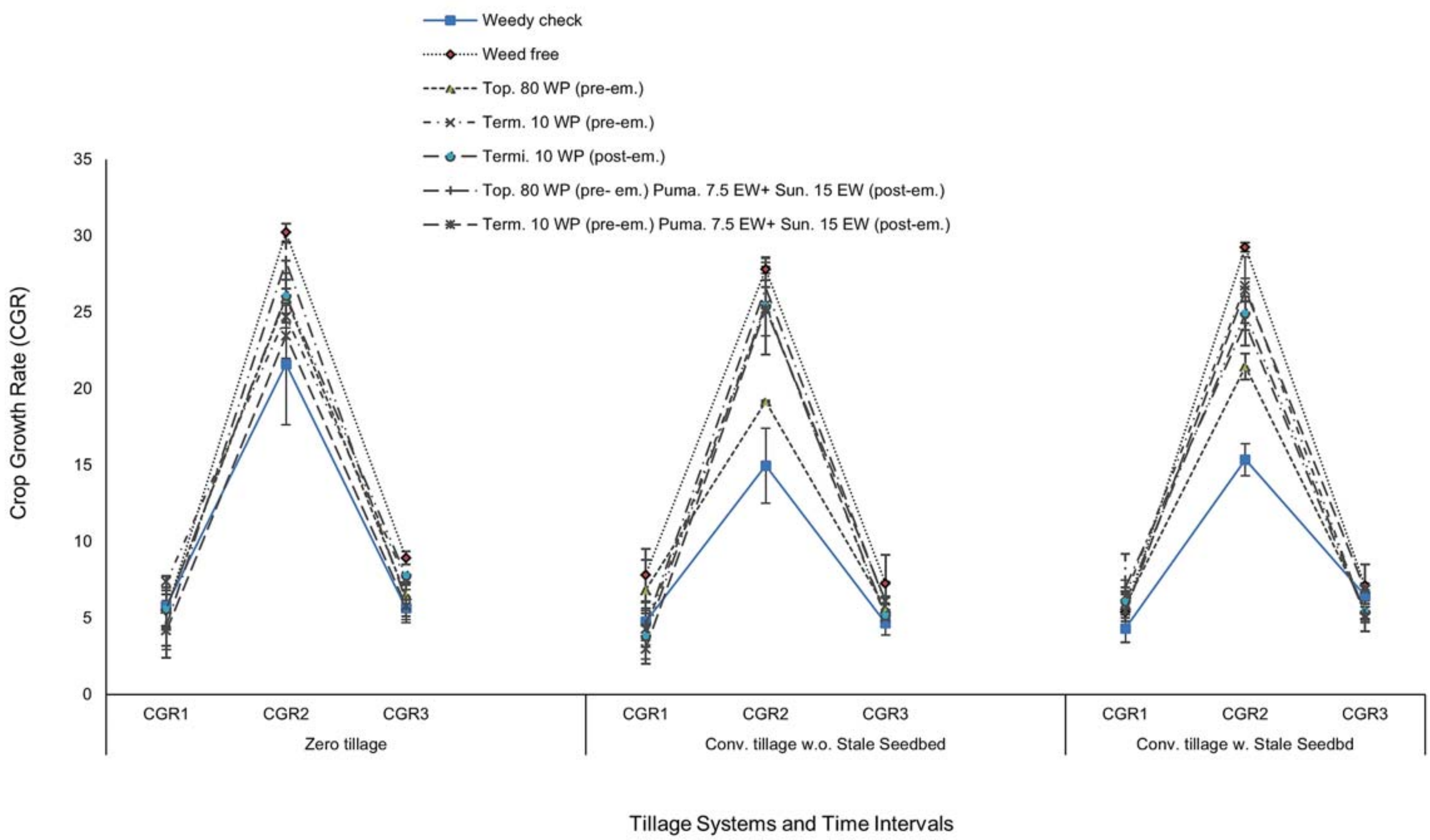

Figure 3 - Influence of weed management treatments on Crop Growth Rate (CGR) (gm^{-2} day^{-1}) in aerobic rice grown under different tillage systems.

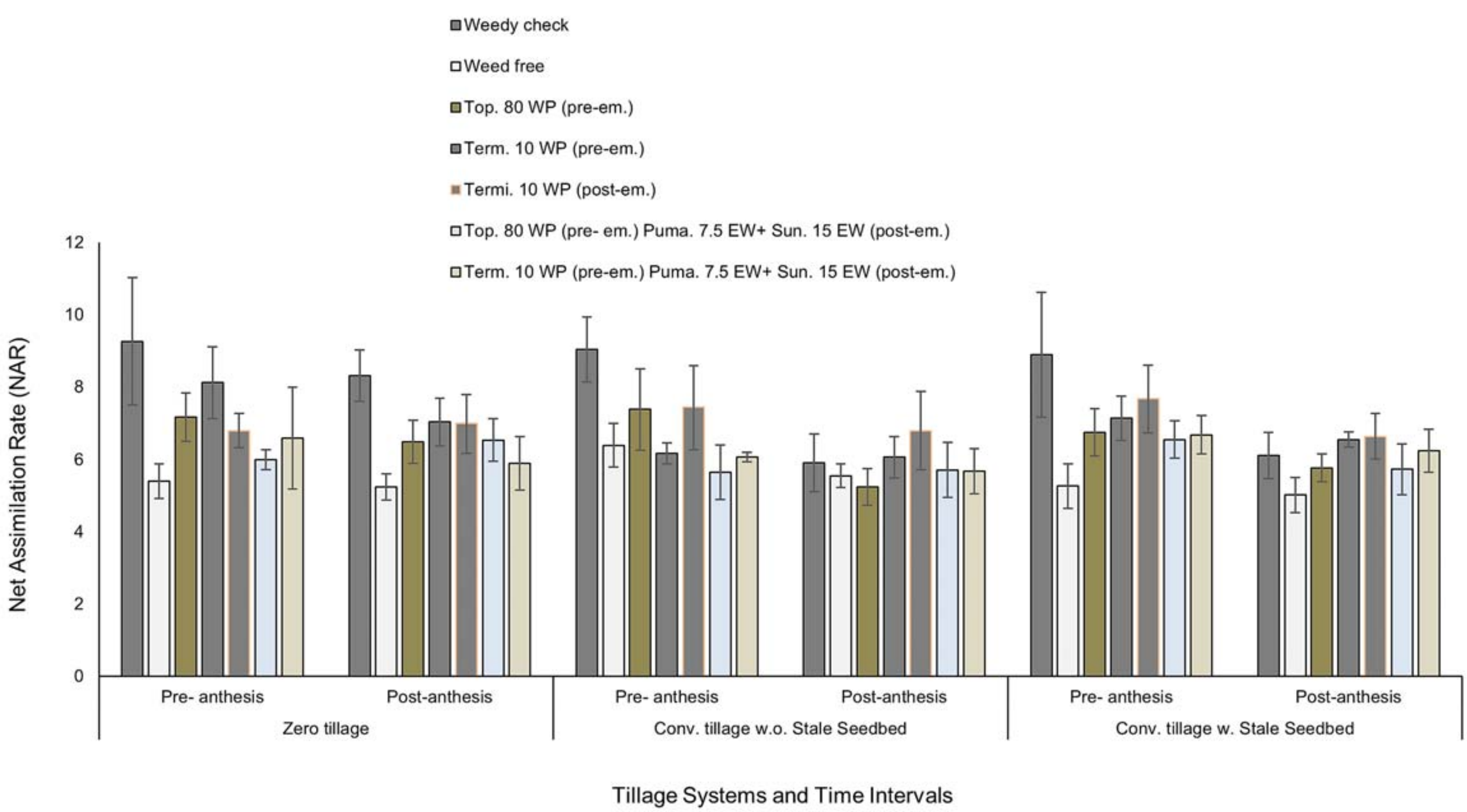

Figure 4 - Influence of weed management treatments on Net Assimilation Rate (NAR) (gm^{-2} day^{-1}) in aerobic rice grown under different tillage systems.

(post-emergence) and oxadiargyl (pre-emergence)+ fenoxaprop-ethyle + sodium fluoride (post-emergence) and maximum CGR and NAR were observed for herbicide pyrazosulfuron (pre- and post-emergence) and minimum values were recorded in case of weedy check plots, which was most probably due to more competition of weeds and low resources availability in these plots (Khaliq et al., 2001). Among tillage systems, herbicides efficacy was higher in conventional tillage than under zero tillage system (Chauhan and Opena, 2012) and gave better yield of rice than zero tillage system. These results are in line with the findings of Chauhan et al. (2013).

Agronomic traits of rice

Data regarding total number of tillers recorded at maturity (Table 3) showed that it varied significantly ($p<0.05$) with weed control treatments. Partial weedy check treatment recorded minimum number of tillers. However, herbicide application and weed free treatments improved total number of tillers. Nevertheless, maximum number of tiller (414.55 m^{-2}) was recorded in weed free treatments and was 52% more than control (196.22 m^{-2}). Among herbicides treatments, Terminator 10 WP (pre-emergence) recorded maximum number of tillers (343.08 m^{-2}). Application of these herbicides gave 42% more tillers as compared with weedy check treatment. However, herbicide application and weed free treatments improved total number of tillers. Nevertheless, maximum number of tiller (370 m^{-2}) was recorded in weed free treatments and 55% more than weed check (control).

Among herbicides treatments Terminator 10 WP (pre-emergence) recorded maximum number of tillers (309.08 m^{-2} and46% more recorded productive tillers as compared with weedy check treatment. Nevertheless, maximum number of non-productive tillers (44 m^{-2}) was recorded in weed free treatments and 31% more than weed check treatments. Among herbicide treatments Top star 80 WP (pre-em.) followed by Puma super 7.5 EW+ Sun star 15 EW (post-em.) recorded maximum number of non-productive of tillers (35.55 m^{-2}) and 15% more as compared to weed check treatments. Partial weedy check treatment recorded minimum number of non-productive tillers (30 m^{-2}).

Table 3 - Influence of tillage systems and weed management practices on agronomic traits in aerobic rice

Tillage system	Plant height (cm)	Total number of tillers (m^{-2})	Non-productive tillers (m^{-2})	Productive tillers (m^{-2})	Panicle length (m^{-2})	Number of branches per panicle	Number of kernels per panicle	1000 kernels weight (g)	Biological yield (ton ha^{-1})	Kernels yield (ton ha^{-1})	Normal kernels	Opaque kernels (%)	Chalky kernels	Abortive kernels
Zero tillage	85.08	310.24	34.71	275.52	21.59 A	9.47	73.46	17.17 C	12.07	2.96	60.97	13.44	12.15	13.63
Conventional tillage without stale seed bed	91.11	307.14	36.14	271.00	21.77 A	9.47	73.38	18.22 B	12.16	2.87	62.88	13.84	12.82	14.44
Conventional tillage with stale seed bed	97.65	312.24	36.24	276.00	22.66 B	9.51	73.46	19.20 A	12.39	2.99	60.29	13.73	13.01	14.78
Weed management practices														
Weedy check	90.27	196.22 D	30.89 C	165.33 D	21.62	8.12 D	62.78 C	16.78 C	6.78 C	1.45 C	43.77 C	18.51 A	17.66 A	22.64 A
Oxadiargyl (pre-emergence)	84.74	414.55 A	44 A	370.55 A	22.40	10.41 A	83.72 A	19.15 A	15.58 A	3.45 A	71.54 A	10.47 C	9.31 C	9.11 C
Pyrazosulfuron (pre-emergence)	93.11	302.88 BC	34.88 B	268 BC	21.62	9.42 C	73.37 B	18.2 AB	12.20 B	3.20 AB	63.72 B	13.04 B	13.22 B	13.27 B
Pyrazosulfuron (post-emergence)	93.04	343.44 B	34.22B	309.22B	22.42	9.59 BC	75.15 B	18.19 AB	13.06 B	3.07 B	62.32 B	13.31 B	12.81 B	12.92 B
Oxadiargyl (pre- emergence) + fenoxaprop-ethyle + sodium fluoride (post-emergence)	92.50	320.55BC	35.22 B	285.33BC	22.01	9.46 BC	73.61 B	17.86 B	12.85 B	3.14 AB	64.98 B	12.81 B	11.68 B	14.82 B
Pyrazosulfuron (pre-emergence) + fenoxaprop-ethyle + sodium fluoride (post-emergence)	92.51	303.33 BC	35.55 B	267.77BC	21.98	9.72 B	72.3 B	18.91 AB	12.16 B	3.12 AB	62.46 B	14.04 B	12.41 B	14.21 B
Weed free (manual weeding)	92.79	288.11 C	35.11B	253 C	22.01	9.62 BC	73.07 B	18.3 AB	12.80 B	3.14 AB	60.84 B	13.46 B	11.71 B	13.83 B

In Conventional tillage with stale seedbed recorded significantly ($p<0.05$) more panicle length of 22.66 cm. Zero tillage recorded 4% less panicle length (21.59 cm) as compared to conventional tillage with stale seed bed. Minimum number of branches per panicle (8.12) was recorded in weed check plots. Weed free plots was recorded maximum number of branches per panicle (10.41) and 22% more than weed check treatments. Among the herbicides application maximum number of branches per panicle (9.72) recorded with Top star 80 WP (pre-emergence), followed by Puma super 7.5 EW+ Sun star 15 EW (post-emergence) and 17% more as compared to weed check treatments. Minimum kernels per panicle (62.78) were recorded for weed check plots. Weed free plots was recorded maximum number of kernel per panicle (83.72) and 26% more than weed check treatments. Among the herbicides application maximum kernel per panicle (75.37) recorded with Terminator 10 WP applied at pre emergence stage and 16% more number of kernels per panicle as compared to weed check treatment.

Data regarding 1000 kernel weight (g), biological yield and kernel yield varied significantly ($p<0.05$) for weed management treatments (Table 3). Minimum 1000 kernels weight (16.78 g) was recorded in weed check plots. Among the herbicides applied, maximum 1000 kernel weight (19.15 g) was recorded where pyrazosulfuron applied at the pre-emergence stage while fenoxaprop-ethyle + sodium fluoride (post-emergence) enhanced 1000 kernel weight by 8% over the weedy check. In addition, data regarding biological yield, the maximum value (15.58 ton ha^{-1}) was recorded in oxadiargyl (pre-emergence), around 58% higher than that of weedy check plots, followed by pyrazosulfuron (post-emergence) (13.06 ton ha^{-1}; Table 3). Similarly, maximum kernel yield values was recorded in oxadiargyl (pre-emergence) (3.45 ton ha^{-1}) which is approximately 57% more than that of weedy check plots (1.45 ton ha^{-1}). Pyrazosulfuron (pre-emergence) exhibited a kernel yield of 3.20 ton ha^{-1} approximately 48% higher than weedy check plots.

Quality traits of rice kernels

The application of herbicides as pre-emergence and post-emergence in aerobic rice showed performance. Herbicides treated plots showed significantly ($P<005$) increased plant height than weedy check most probably due to accessibility of complimentary conditions for growth produced by herbicides by eliminating weeds as described by Mann et al. (2007).

Data regarding normal, opaque, chalky and abortive kernels percentage varied significantly ($p<0.05$) among different weed management practices, whereas the main effect of tillage systems and their interactions with herbicides were non-significant ($p<0.05$) (Table 3). Weedy check treatments exhibited minimum normal kernels (43.777%). Maximum normal kernels (71.54%) were recorded for weed free treatments. Among herbicides tested, pyrazosulfuron (post-emergence) treated plots recorded higher percentage of normal kernels (64.98%) which was statistically at par with other herbicides. In case of abortive kernels, weedy check treatment scored maximum value (22.64%) and minimum abortive kernels (9.11%) were recorded for weed free treatment. Among herbicides, pyrazosulfuron (pre-emergence) treated plots gave lower percentage of abortive kernels. Similarly, regarding chalky kernels, weedy check treatments produced maximum value (17.66%) while minimum chalky kernel value (9.31%) was found for weed free treatments. Among herbicide applications, pyrazosulfuron (pre-emergence) and fenoxaprop-ethyle + sodium fluoride (post-emergence) exhibited lower chalky kernels (11.71%). Likewise, weedy check treatments scored maximum opaque kernels (18.51%) while minimum opaque kernels (10.41%) were recorded for weed free treatments. Among herbicides, maximum of opaque kernels (14.47%) were recorded for oxadiargyl (pre-emergence) + fenoxaprop-ethyle + sodium fluoride (post-emergence).

Our findings are consistent with those of Sharma et al. (2004) and Mann et al. (2007) who also reported the same trend. Treatments under both zero and conventional tillage gave higher weed control than control plots. A total number of tillers and productive tillers were relatively higher in herbicides treated plots than control plots. Mubeen et al. (2014) recorded significant reduction in a number of tillers in rice due to the season-long weed. High weed control was recorded in treatments under zero and conventional tillage than control plots. Herbicides treated plots were showed maximum number of total and productive tillers than control plots. Mubeen et al. (2014) said that due to the season long weed competition reduced in number of tillers.

Ahmad and Chauhan (2014) and Khaliq et al. (2012a) also recorded more productive tillers and kernels per panicle in herbicides treated plots. Results of the study indicated that manual weeding and herbicides application not only increased rice yield but also improve its quality. This might be favoured by more efficient and uniform distribution of fertilizers and photo-assimilates causing more chalky, opaque, normal kernels and less abortive on direct-seeded rice (Khaliq et al., 2011, 2012).

Economic analysis and benefit cost ratio

Economic analysis is the criteria for basic determination of net benefits. The economic analysis of weed management under different tillage systems and treatments applied on DSR crop is important to be considered from farmers' point of view as they are more interested net benefit or returns. Maximum benefit cost ratio (BCR) of 1.85 was calculated for weed free treatment under zero tillage system (Table 4). Among herbicide applications, pyrazosulfuron at post-emergence stage under zero tillage system recorded maximum (1.72) BCR. Total cost of production was less grass income than partial weedy check treatments. Hence, these showed negative values of net returns and BCR values less than 1 (0.72, 0.65 and 0.91) (Table 4).

Table 4 - Benefit cost ratio for aerobic rice under different tillage and weed management practices

Tillage system	Weed control treatment	Variable cost (USD$ ha^{-1})	Fixed cost (USD$ ha^{-1})	Total cost (USD$ ha^{-1})	Gross income (USD$ ha^{-1})	Net field benefit (USD$ ha^{-1})	Net return (USD$ ha^{-1})	BCR (%)
Zero tillage	Weedy check	55.75	826.38	882.13	631.20	575.45	-250.93	0.72
	Weed free	145.75	826.38	972.13	1802.70	1656.95	830.57	1.85
	Oxadiargyl (pre-emergence)	54.25	826.38	880.63	1480.50	1426.25	599.87	1.68
	Pyrazosulfuron (pre-emergence)	56.25	826.38	882.63	1485.90	1429.65	603.27	1.68
	Pyrazosulfuron (post-emergence)	56.25	826.38	882.63	1555.20	1498.95	672.57	1.76
	Oxadiargyl (pre- emergence) + fenoxaprop-ethyle + sodium fluoride (post-emergence)	82.75	826.38	909.13	1498.50	1415.75	589.37	1.65
	Pyrazosulfuron (pre-emergence) + fenoxaprop-ethyle + sodium fluoride (post-emergence)	84.75	826.38	911.13	1449.90	1365.15	538.77	1.59
Conventional tillage with stale seed bed	Weedy check	105.00	82638	931.38	609.00	504.00	-322.38	0.65
	Weed free	195.00	826.38	1021.38	1535.40	1340.40	514.02	1.50
	Oxadiargyl (pre-emergence)	103.50	826.38	929.88	1558.80	1455.30	628.92	1.68
	Pyrazosulfuron (pre-emergence)	105.50	826.38	931.88	1406.70	1301.20	474.82	1.51
	Pyrazosulfuron (post-emergence)	105.50	826.38	931.88	1462.50	1357.00	530.62	1.57
	Oxadiargyl (pre- emergence) + fenoxaprop-ethyle + sodium fluoride (post-emergence)	132.00	826.38	958.38	1483.20	1351.20	524.82	1.55
	Pyrazosulfuron (pre-emergence) + fenoxaprop-ethyle + sodium fluoride (post-emergence)	134.00	826.38	960.38	1567.80	1433.80	607.42	1.63
Conventional tillage without stale seed bed	Weedy check	125.00	826.38	951.38	868.80	743.80	-82.58	0.91
	Weed free	215.00	826.38	1041.38	1649.70	1434.70	608.32	1.58
	Oxadiargyl (pre-emergence)	123.50	826.38	949.88	1528.20	1404.70	578.32	1.61
	Pyrazosulfuron (pre-emergence)	125.50	826.38	951.88	1525.50	1400.00	573.62	1.60
	Pyrazosulfuron (post-emergence)	125.50	826.38	951.88	1484.10	1358.60	532.22	1.56
	Oxadiargyl (pre- emergence) + fenoxaprop-ethyle + sodium fluoride (post-emergence)	152.00	826.38	97838	1478.70	1326.70	500.32	1.51
	Pyrazosulfuron (pre-emergence) + fenoxaprop-ethyle + sodium fluoride (post-emergence)	154.00	826.38	98038	1478.70	1324.70	498.32	1.51

Dominance analysis

On the basis of net field benefits, final recommendation for production technology cannot be specified. Dominance is a mechanism for identification of good alternatives. Data given in Table 5 indicated net field benefit of some treatments were less than those with the lower cost rendering these treatments dominated (D) and the remaining others (un-dominated).It is concluded that applications of oxadiargyl (pre-emergence) followed by fenoxaprop-ethyle + sodium fluoride (post-emergence) is an efficient approach to increase the DSR rice kernel yield under conventional tillage without stale seed bed, while herbicide pyrazosulfuron exhibits maximum net benefit (USD$ 817 ha^{-1}) and benefit to cost ratio (1.76) under zero tillage system when applied at pre- and post-emergence stage.

Table 5 - Marginal analysis for aerobic rice under different tillage and weed management practices. (* D = dominated)

Tillage system	Weed control treatment	Variable cost (USD$ ha^{-1})	Net field benefit (USD$ ha^{-1})	Marginal cost (USD$ ha^{-1})	Marginal net benefit (USD$ ha^{-1})	Marginal rate of return (%)
Zero tillage	Weedy check	55.75	575.45			D*
	Oxadiargyl (pre-emergence)	54.25	1426.25			
	Pyrazosulfuron (pre-emergence)	56.25	1429.65	0.50	854.20	1708.42
	Pyrazosulfuron (post-emergence)	56.25	1498.95		69.30	D
	Oxadiargyl (pre- emergence) + fenoxaprop-ethyle + sodium fluoride (post-emergence)	82.75	1415.75	26.50		D
	Pyrazosulfuron (pre-emergence) + fenoxaprop-ethyle + sodium fluoride (post-emergence)	84.75	1365.15		D	D
	Weed free	145.75	1656.95	61.00	291.80	4.78
Conventional tillage with stale seed bed	Weedy check	105.00	504.00			D
	Oxadiargyl (pre-emergence)	103.50	1455.30			
	Pyrazosulfuron (pre-emergence)	105.50	1301.20		797.20	
	Pyrazosulfuron (post-emergence)	105.50	1357.00			D
	Oxadiargyl (pre- emergence) + fenoxaprop-ethyle + sodium fluoride (post-emergence)	132.00	1351.20			
	Pyrazosulfuron (pre-emergence) + fenoxaprop-ethyle + sodium fluoride (post-emergence)	134.00	1433.80			D
	Weed free	195.00	1340.40			D
Conventional tillage without stale seed bed	Weedy check	125.00	743.80			D
	Oxadiargyl (pre-emergence)	123.50	1404.70			
	Pyrazosulfuron (pre-emergence)	125.50	1358.60		614.80	D
	Pyrazosulfuron (post-emergence)	125.50	1400.00	0.50	41.40	8280
	Oxadiargyl (pre- emergence) + fenoxaprop-ethyle + sodium fluoride (post-emergence)	152.00	1326.70			D
	Pyrazosulfuron (pre-emergence) + fenoxaprop-ethyle + sodium fluoride (post-emergence)	154.00	1324.70			D
	Weed free	215.00	1434.70	61.00	110.00	180.33

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